

## QA/QC

**Initials**

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Originated By:

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1/11/22

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January 11, 2022

PS19-20316-0

Brian Bell  
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Renton, Washington 98055

Subject: **Geotechnical Recommendations for Bridge 40P – Geofoam – WSDOT FINAL**  
WSDOT I-405: Renton to Bellevue Widening and Express Toll Lanes Project  
Renton, Washington

Dear Mr. Bell:

This letter provides the stress distribution calculations supporting the selection of the geofoam grade used for subgrade specified in the “Released for Construction” version of the I-405 R2B BR-ERC New Eastside Rail Corridor Over SB I-405 plans (David Evans and Associates dated April 13, 2021) (submittal number 1243).

The geofoam design was completed in accordance with National Cooperative Highway Research Program Report 529 (NCHRP 529), Guideline and Recommended Standard for Geofoam Applications in Highway Embankments (2004), and the associated Web Document 65 (2004). The evaluation is needed to assure that the expanded polystyrene (EPS) block fill can support the overlying pavement system without excessive settlement, which could occur if the vertical stress from the live loads and pavement system exceeds the elastic limit of the EPS geofoam.

The following design assumptions were made to evaluate the load bearing capacity of EPS geofoam blocks:

- Traffic load: American Association of State Highway and Transportation Officials (AASHTO) HS20 equivalent per C3.6.1.3.2 of AASHTO, with an axle load of 32 kips, and a load of 16 kips per dual set of tires.
- Impact Coefficient: 0.3 per NCHRP 529
- Typical tire pressure for legal highway trucks with single and dual tires ranges from 60 to 90 pounds per square inch (psi), therefore 90 psi was used for design purposes.
- One-foot-thick pavement section of 6 inches of gravel base (crushed surfacing base course [CSBC]) and 6 inches of hot mix asphalt (HMA) surfacing to comply with the project specified pavement section.

The material properties used for the HMA and CSBC are consistent with the recommendations from the Web Document. The program (KENLAYER) used to calculate the stress distribution in the Web Document is not licensed for professional use. Therefore, to adopt the recommended approach of using an elastic layered solution that accounts for the influence of layers with different elastic properties, the multi-layer solution within Settle3 was used. The assumed material properties are provided in Table 1. These properties are consistent with the recommended values in NCHRP 529, and values provided by EPS manufacturers for EPS46. The stresses at the bottom of each layer are also provided in Table 1.

**Table 1: Geofoam Supported Pavement Profile Properties and Results**

Material	Unit Weight (pcf)	Youngs Modulus (psi)	Poisson's Ratio	Layer Thickness (ft)	Stress at Bottom of Layer (psi)
Asphalt (HMA)	148	100,000	0.46	0.5	24
Gravel Base (CSBC)	138	3,000	0.35	0.5	14.5

Material	Unit Weight (pcf)	Youngs Modulus (psi)	Poisson's Ratio	Layer Thickness (ft)	Stress at Bottom of Layer (psi)
Geofoam (EPS46)	2.85	1,860	0.258	1	7.46

Abbreviations

pcf = pounds per cubic foot  
psi = pounds per square inch  
ft = feet

The maximum stress applied to the EPS through the pavement profile is 14.5 psi, which is less than the allowable stress of 15.5 psi for EPS46, which includes a factor of safety of 1.2. This analysis confirms that the geofoam specified in the above referenced bridge plans adequately supports the design stresses of the pavement profile and project loading.

We completed this work in general accordance with our contract with Wood Environment & Infrastructure Solutions, Inc. (Wood), dated October 31, 2019. This letter is for the exclusive use of Wood, the Washington State Department of Transportation (WSDOT), and the design-build team for specific application to this project and site. We completed this work in accordance with generally accepted geotechnical practices for the nature and conditions of the work completed in the same or similar localities, at the time the work was performed. We make no other warranty, expressed or implied.

Please feel free to contact us if you have any questions concerning this letter.

Sincerely,

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**Attachments:**

Appendix A – Calculation Package

JRJ/BJE/JJW

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**References**

National Cooperative Highway Research Program (NCHRP), 2004. *Guideline and Recommended Standard for Geofoam Applications in Highway Embankments*. Washington, D.C.

National Cooperative Highway Research Program (NCHRP) Web Document 65, 2004. *Geofoam Applications in the Design and Construction of Highway Embankments*. Washington, D.C.

**FLATIRON**



**wood.**

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## **Appendix A**

### **Calculation Package**

## Description

InsulFoam® GF (Geofoam) is a high-performance, lightweight, geosynthetic fill material consisting of closed cell expanded polystyrene (EPS). Geofoam is the common industry term for InsulFoam GF and similar products. InsulFoam GF is manufactured from the same high-quality blocks as our InsulFoam brand insulations and meets or exceeds the requirements of ASTM D6817, Standard Specification for Rigid Cellular Polystyrene Geofoam. InsulFoam GF is manufactured in a common density range between .70 to 2.85 lb/ft³ (11.2-45.7 kg/m³) and is an ideal, lightweight fill alternative for many construction applications.

## Uses

InsulFoam GF is commonly used in areas where unstable soil conditions exist and as an alternative to various fill materials. The unique load disbursement and lightweight characteristics of InsulFoam GF help to minimize any post-construction settling. InsulFoam GF is also used as backfill to reduce lateral earth pressure behind adjacent structures such as retaining walls. InsulFoam GF is successfully used in the following engineered applications:

- Roads & Highways
- Bridge Approaches
- Retaining Walls
- Berms & Embankments
- Loading Docks & Ramps
- Landscaping
- Dikes & Levees
- Foundations
- Parking Structures
- Buried Utilities Protection
- Compressible Inclusions

## Advantages

- **Lightweight.** With typical densities from .70 to 2.85 lb/ft³ (11.2 - 45.7 kg/m³), InsulFoam GF is significantly lighter than soil (approximately 120 lb/ft³).
- **Cost Effective.** The lightweight nature of InsulFoam GF can reduce or eliminate the need for heavy earth moving and compaction equipment. The InsulFoam GF blocks can be easily picked up and placed manually. At sites with rough terrains or poor access, InsulFoam GF blocks can be transported, handled and placed faster than soil and other fills.
- **Environmentally Safe.** InsulFoam GF contains no ozone depleting CFCs, HCFCs, or formaldehyde. It is an inert and highly stable product that will not decompose, decay or produce undesirable gasses or leachates. InsulFoam GF is recycleable and save for waste-to-energy (WTE) systems and landfills.
- **Insect and Mold Resistant.** InsulFoam GF can be manufactured with an inert additive that repels termites and carpenter ants. InsulFoam GF does not sustain mold and mildew growth.

## LIGHTWEIGHT STABILITY SIMPLIFIED.

- **Proven Performer.** For over 50 years engineers have been successfully using Geofoam worldwide. It's currently approved for use by the Federal Highway Administration (FHWA), many state Departments of Transportation (DOT) and other government and private entities.
- **Weather Resistant.** InsulFoam GF can be transported, handled and installed in most weather conditions and is unaffected by freeze-thaw cycling, moisture and road salts. Other fill materials such as wood chips, saw dust, lightweight concrete and soil can be weather sensitive during installation.
- **Maintenance Free.** Under normal conditions, InsulFoam GF requires no maintenance for the life of the fill system.
- **Homogenous Make-up.** InsulFoam GF is manufactured with consistent properties throughout individual blocks. Other lightweight fill materials (such as used tires, wood chips and fibers) can be varied and inconsistent in their make-up. Such inconsistencies can result in non-uniform load transfer and differential settlement.
- **No Preloading.** Unlike other fill materials, InsulFoam GF does not require surcharging, preloading or staged construction.

## Product Features

- **Job Specific Sizes.** InsulFoam GF is manufactured to meet job specific requirements. With varying maximum block-sizes available from the Insulfoam facilities, it is important the designer contact the local Insulfoam Representative to determine maximum block sizes for each project.
- **Adaptable.** If jobsite block size adjustments are needed, InsulFoam GF can easily be cut on-site with hot wire tooling or saws.
- **Clear Product Marketings.** Each InsulFoam GF block is marked with the manufacture date, location, ASTM designation and density.



## Design Considerations

- For InsulFoam GF applications, design load stresses should not exceed 1% strain for combined live and dead loads.
- In conditions where InsulFoam GF is periodically subjected to submergence from fluctuating ground water, add 1.87 lb/ft<sup>3</sup> (30 kg/m<sup>3</sup>) to the InsulFoam GF design density.
- In conditions where InsulFoam GF is continually below ground water, add 5.00 lb/ft<sup>3</sup> (80kg/m<sup>3</sup>) to the InsulFoam GF design density.
- In earth work applications (such as levees, dikes and berms) uplift buoyancy forces must be considered. The buoyancy force must be counteracted with overburden or restraint devices with geogrids or geomembranes.



## LIGHTWEIGHT STABILITY SIMPLIFIED.

## Installation Recommendations

- InsulFoam GF contains a flame retardant additive; however, it shall be considered combustible and should not be exposed to open flame or any source of ignition.
- Protect InsulFoam GF from exposure to hydrocarbons, highly solvent extended mastics and coal tar.
- If long-term (6 months or greater) outside storage is necessary, InsulFoam GF should be covered with a light colored opaque material. Exposure to UV may cause surface discoloration but does not effect physical properties.
- Blocks of InsulFoam GF should be placed tightly on a prepared leveling course.
- If multiple layers of InsulFoam GF are required, orient the successive layers with the long axis at 90° to the previous layer.
- Use InsulGrip plates during inclement weather to provide horizontal restraint between layers of InsulFoam GF and to help keep the product from shifting.
- In windy conditions, InsulFoam GF should be ballasted during storage and upon installation.
- Heavy equipment should not operate directly on the surface of the InsulFoam GF.

## Typical Tested Physical Properties of InsulFoam Geofoam\*

Type - ASTM D6817	Units	EPS12	EPS15	EPS19	EPS22	EPS29	EPS39	EPS46
<b>Density</b> (min. pcf)	lb/ft <sup>3</sup> (kg/m <sup>3</sup> )	0.70 (11.2)	0.90 (14.4)	1.14 (18.4)	1.35 (21.6)	1.80 (28.8)	2.40 (38.4)	2.85 (45.7)
<b>Compressive Resistance</b> ** min. @ 1% deformation	psi (kPa)	2.2 (15)	3.6 (25)	5.8 (40)	7.3 (50)	10.9 (75)	15.0 (103)	18.6 (128)
<b>Flexural Strength</b> (min. psi)	psi (kPa)	10.0 (69)	25.0 (172)	30.0 (207)	40.0 (276)	50.0 (345)	60.0 (414)	75.0 (517)
<b>Oxygen Index, min.</b>	Volume %	24.0	24.0	24.0	24.0	24.0	24.0	24.0
<b>Dimensional Stability</b>	max. %	< 2%	< 2%	< 2%	< 2%	< 2%	< 2%	< 2%
<b>Buoyancy Force</b>	lb/ft <sup>3</sup> (kg/m <sup>3</sup> )	61.7 (990)	61.5 (980)	61.3 (980)	61.1 (980)	60.6 (970)	60.0 (960)	59.5 (950)
<b>Poisson's Ratio</b>	--	.05	.05	.05	.05	.05	.05	.05
<b>Coefficient of Friction</b>	--	.6	.6	.6	.6	.6	.6	.6
<b>Absorption by Total Immersion</b>	Volume %	< 4.0	< 4.0	< 3.0	< 3.0	< 2.0	< 2.0	< 2.0
<b>Elastic Modulus, min.</b>	psi (kPa)	220 (1500)	360 (2500)	580 (4000)	730 (5000)	1090 (7500)	1500 (10300)	1860 (12800)

\*Properties are based on data provided by resin manufacturers, independent test agencies and Insulfoam.

\*\* The design load stresses should not exceed 1% strain for combined live and dead loads for InsulFoam GF applications.

## Loading calculations:

Axle load = 32 kips. Dually tires (4 tires per axle). Live Load per side =  $32/2 = 16$  kips

$$QD = LL * (1+I) = 16 * 1.3 = 20.8 \text{ kips (eq 6.3)}$$

### Step 2: Add impact allowance to traffic loads

Allowance for impact forces from dynamic, vibratory, and impact effects of traffic are generally only considered where they act across the width of the embankment or adjacent to a bridge abutment. In (I) an impact coefficient of 0.3 is recommended for design of EPS-block geofoam. Equation (6.3) can be used to include the impact allowance to the live loads estimated in Step 1 if impact loading is deemed necessary for design:

$$Q = LL * (1+I) = 1.3 (LL) \quad (6.3)$$

where  $Q$  = traffic load with an allowance for impact,

$LL$  = live load for traffic from AASHTO standard classes of highway loading (15)

obtained in Step 1, and

$I$  = impact coefficient = 0.3.

$$A_{cd} = 20,800 \text{ lbs}/90 \text{ psi} = 231.11 \text{ inches}^2$$

$$r = (231.11 \text{ inches}^2/\pi)^{0.5} = 8.577 \text{ inches}, 0.71475 \text{ ft.}$$

$$\text{Pressure at ground surface} = 90 \text{ psi} = 12.96 \text{ ksf.}$$

For the case of a single axle with dual tires, the contact area can be estimated by converting the set of duals into a singular circular area by assuming that the circle has an area equal to the contact area of the duals as indicated by Equation (6.6). The radius of contact is given by Equation (6.7). Equation (6.6) yields a conservative value, i.e., smaller area, for the contact area because the area between the duals is not included.

$$A_{CD} = \frac{Q_D}{q} \quad (6.6)$$

$$r = \left( \frac{A_{CD}}{\pi} \right)^{\frac{1}{2}} \quad (6.7)$$

where  $A_{CD}$  = contact area of dual tires

$Q_D$  = live load on dual tires

$q$  = contact pressure on each tire = tire pressure

$$\text{Allowable stress on geofoam with factor of safety of 1.2} = 18.6/1.2 = 15.5 \text{ psi} = 2.232 \text{ ksf}$$



## Pavement material properties:

### *Pavement Systems Used in Developing Design Vertical Stress Charts*

*Asphalt Concrete Pavement System.* Based on the design catalog for flexible pavements, see Table 4.2, an asphalt thickness ranging from 76 to 178 mm (3 to 7 in.) was utilized with a corresponding crushed stone base thickness equal to 610 mm (24 in.) less the thickness of the asphalt. This provides the minimum recommended pavement system thickness of 610 mm (24 in.) to minimize the potential for differential icing and solar heating. For the asphalt concrete, a typical unit weight of 23 kN/m<sup>3</sup> (148 lbf/ft<sup>3</sup>), Poisson's ratio of 0.46, and modulus of elasticity of 689 MPa ( $100 \times 10^3$  lbs/in<sup>2</sup>) were utilized (14). For the crushed stone base, a unit weight of 22

6- 39

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in the Design and Construction of Highway Embankments

kN/m<sup>3</sup> (138 lbf/ft<sup>3</sup>), Poisson's ratio of 0.35, and modulus of elasticity of 21 MPa (3,000 lbs/in<sup>2</sup>) was utilized in KENLAYER. The unit weight and Poisson's ratio was obtained from average values reported in (14). The modulus of elasticity was conservatively based on average values reported in (19) for a loose sand and gravel.

*Poisson's Ratio.* The following findings regarding the Poisson's ratio,  $\nu$ , of EPS block are provided:

- Within the elastic range,  $\nu$  is relatively small (of the order of 0.1) and often taken to be zero for practical design purposes, e.g. in the French national design manual (34). However, if a more accurate estimate of  $\nu$  is desired, the following empirical relationship, which indicates that  $\nu$  increases slightly with increasing EPS density, can be used:

2-33

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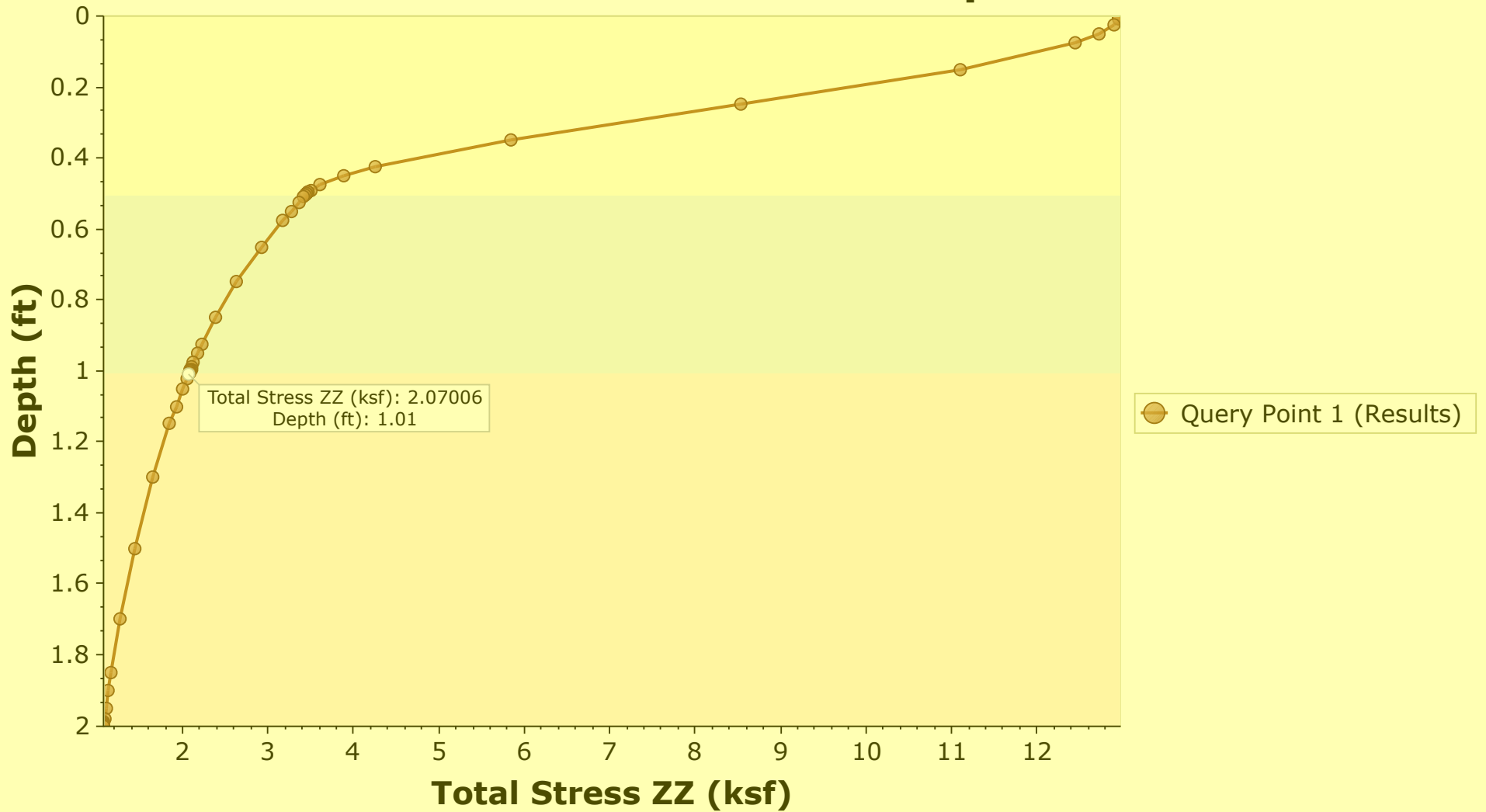
$$\nu = 0.0056 \rho + 0.0024 \quad (2.7)$$

where  $\rho$  = EPS density in  $\text{kg/m}^3$ . This equation is based on research performed in Japan (19).

EPS46 poisson's ratio =  $0.0056 \times 45.7 + 0.0024 = 0.2583 = 0.258$

EPS49 E = 18.6 psi @ 1% strain =  $18.6 / 0.01 = 1860$  psi = 267.8 ksf

# Total Stress ZZ vs. Depth



Reference Stage: None

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

Bridge 40P Geofoam Vertical Stress vs. Depth

19343-01

01/22

**HARTCROWSER**

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Figure

**A-1**



40P geofoam stress calculation  
Report Creation Date: 2022/01/03, 22:05:45

# Table of Contents

Project Settings ..... 3

Stage Settings ..... 4

Results ..... 5

Stage: Results ..... 5

Loads ..... 6

1. Circular Load: "Circular Load 1" ..... 6

Soil Layers ..... 7

Soil Properties ..... 8

Query Points ..... 9

# Settle3 Analysis Information

## 40P geofoam stress calculation

### Project Settings

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Document Name	pavement pressure multi layer 90psi (Recovered)
Project Title	40P geofoam stress calculation
Date Created	2/18/2021, 9:33:42 AM
Stress Computation Method	Multiple Soil Layers
Minimum settlement ratio for subgrade modulus	0.9
Use average poisson's ratio to calculate layered stresses	
Improve consolidation accuracy	
Ignore negative effective stresses in settlement calculations	

## Stage Settings

---

Stage #	Name
1	Results

## Results

Time taken to compute: 0.133703 seconds

### Stage: Results

Data Type	Minimum	Maximum
Total Settlement [in]	0	0.0993767
Total Consolidation Settlement [in]	0	0
Virgin Consolidation Settlement [in]	0	0
Recompression Consolidation Settlement [in]	0	0
Immediate Settlement [in]	0	0.0993767
Loading Stress ZZ [ksf]	0.928262	12.96
Total Stress ZZ [ksf]	1.07411	12.9607
Modulus of Subgrade Reaction (Total) [ksf/ft]	0	1565.8
Modulus of Subgrade Reaction (Immediate) [ksf/ft]	0	1565.8
Modulus of Subgrade Reaction (Consolidation) [ksf/ft]	0	0
Total Strain	0.000235035	0.00781328
Degree of Consolidation [%]	0	0
Pre-consolidation Stress [ksf]	1.07468	12.9604
Over-consolidation Ratio	1	1
Void Ratio	0	0
Hydroconsolidation Settlement [in]	0	0
Undrained Shear Strength	0	0.0202907

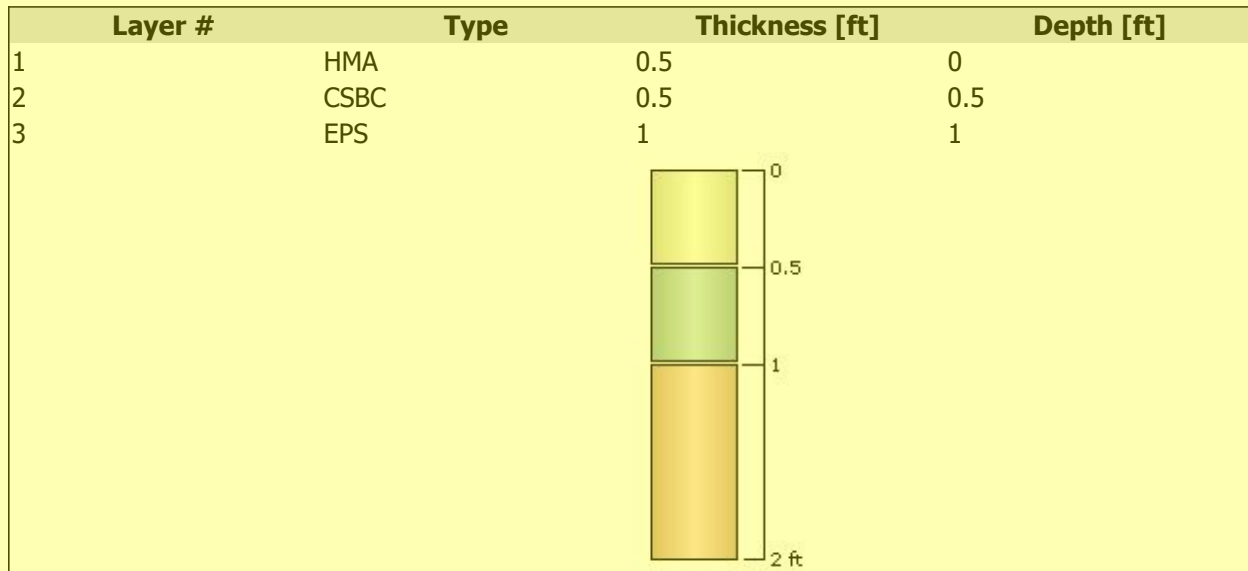


# Loads




## 1. Circular Load: "Circular Load 1"

Radius	0.71475 ft
Center	(-1.90622e-15, 3.02736e-16)
Load Type	Flexible
Area of Load	1.5968 ft2
Load	12.96 ksf
Depth	0 ft
Installation Stage	Results

## Soil Layers



## Soil Properties

Property	HMA	CSBC	EPS
Color			
Unit Weight [kips/ft3]	0.148	0.138	0.00285
K0	1	1	1
Immediate Settlement	Enabled	Enabled	Enabled
Es [ksf]	14400	432	268
Esur [ksf]	14400	432	268
Multiple Stress Option	E from Es = 14400 ksf	E from Es = 432 ksf	E from Es = 268 ksf
Undrained Su A [kips/ft2]	0	0	0
Undrained Su S	0.2	0.2	0.2
Undrained Su m	0.8	0.8	0.8

## Query Points

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Point #	Query Point Name	(X,Y) Location	Number of Divisions
1	Query Point 1	0, 0	Auto: 55